Ecology

Many habitat and land use maps, created even in the 1990's, depict the entire coastal fringe of southwest Collier County as solid areas of mangroves. While it is true that mangroves are the predominant wetland in and around the Reserve and the Ten Thousand Islands, the communities of Rookery Bay National Estuarine Research Reserve and its watersheds are a rich and varied mosaic of saltwater, freshwater and upland ecosystems. There are over 500 plant, 22 mammal, 90 bird, 210 fish, 60 crustacean and 40 reptile and amphibian species documented in the Reserve.

Contents

The plant communities of southwest Florida have been categorized several different ways. Five of these are presented in Davis (1943). Florida Natural Areas Inventory (FNAI) and the contributors to Ecosystems of Florida (Meyers and Ewel, 1990) have suggested more recent classifications for all of Florida. A classification scheme that is appropriate for a specific Reserve, however, needs to meet criteria determined by management issues, scale of management or research, and site-specific structure and function. This section presents 22 classifications based on pertinent management practices, primarily fire and inundation requirements, and, in some instances, susceptibility to exotic plant colonization. The descriptions provided are based on vegetation because this is the easiest recognizable feature. More detailed species lists, both flora and fauna, are provided, but gaps in completeness exist. These descriptions have been tailored to specific findings in the RBNERR communities representative of each class where available.

Terrestrial and Freshwater

Scrub
Pine Scrub
Palm Oak Hammock
Tropical Harwood Hammock
Pine Flatwoods
Cypress Prairie
Cypress Strand
Cypress Dome
March, flatwood
Marsh, wet prairie
Developed

The majority of acreage landward of the mangrove/saltmarsh fringe managed by Rookery Bay National Estuarine Research Reserve (RBNERR) is pine flatwoods. Scrub and freshwater marsh are the next largest communities represented. There are small holdings of cypress, palm-oak hammocks and abandoned agriculture, and a few very small examples of tropical hardwood hammocks. Many of these communities have wide ecotonal margins, and occasionally, a surprise to newcomers in the area, upland and freshwater communities stand directly adjacent to mangroves and saltmarshes.

John Davis, in his 1943 USGS publication, was one of the first scientists to document the extent and composition of natural communities in south Florida. His work, although narrative and largely anecdotal, gave a good description of the mosaic of habitats and the soils that supported them that were prevalent throughout the area. However, because Rookery Bay NERR's mangroves are a unique opportunity for research, the Reserve's upland and watershed community functions are largely undocumented by any scientists. Of the remaining communities, cypress stands, only a small percentage of RBNERR's holdings, have extensive evaluations in nearby areas. Inventories and species lists abound for other communities, but empirical data on structure and function specific to the Rookery Bay area or southwest coast are scarce.

Terrestrial Research

Pine flatwoods have the highest diversity of any south Florida community – 361 species compared to 306 in hardwood hammocks (Beever and Dryden 1993). This hydric community is considered by some to be a rare success ional stage between marsh and hardwood hammock (Duever 1976). Another theory suggests that hydric pines are a distinct south Florida habitat well adapted to cycles of flood, drought and fire (Beever 1993). This seasonally wet forest is a jurisdictional wetland at the federal level, but not for the state of Florida. During the wet summer season, periphyton mats can become as thick as 4 cm (Beever and Dryden 1993). Due to the algal cycle of productivity and respiration, abiotic factors in the forest floor exhibit significant diurnal fluctuations, similar to wetlands and shallow lakes. This community is prime habitat for the endangered Florida panther, the Florida black bear and red-cockaded woodpeckers (Beever and Dryden 1993; Kautz 1994). Twenty-three percent of southwest Florida's pineland was lost to agriculture and urban development between 1943 and 1970 (Birnhak 1974). The remaining stands are susceptible to melaleuca competition, especially along edges of fragmented parcels (Myers 1984).

Cypress forests are a significant part of the southwest Florida landscape. However some ecologists believe that cypress has expanded into a geographic region "to which it is not particularly adapted" (Myers 1984), and that the introduction of *Melaleuca quinquenervia* is forcing it back to areas with more optimal conditions. Southern cypress trees have two leaf variations, creating some dissension about number of species. One viewpoint supports two species, bald cypress (Taxodium distichum) and pond cypress (Taxodium distichum var. nutans or Taxodium ascendens) (Myers 1984, Ewel and Odum 1984, Brown et al. 1984), and the other recognizes only bald cypress with leaf variations arising from extreme environmental conditions (Duever et al. 1984). Three different landscape formations of cypress are obvious in Collier County, and RBNERR has small examples of all three within the Reserve boundary. Studies conducted between 1972 and 1976 in the Belle Meade watershed (Brown et al. 1984) and Fakahatchee Strand (Burns 1984) show that strand cypress has the highest productivity (158 to 180 tonnes biomass/ha), followed by drier domes (80 to 95 tonnes/ha) with prairies, or shrub cypress, having the lowest total production (~30 tonnes/ha/yr). This community is a preferred habitat for the Florida panther (Kautz 1994).

Research on other upland and freshwater communities within the RBNERR boundaries has been conducted on communities much farther to the east and north, and laying on different substrates, subject to different hydrology regimes. These findings may or may not apply to RBNERR's geographical location, ,and consequently, are not presented here.

Scrub

This community includes oak scrub, rosemary scrub, coastal oak and palmetto scrub, but pine scrub is a separate category due to a different fire interval. Scrub is found on higher elevations and excessively well-drained soils, but not always white or light colored sands. It is rarely inundated. The most extensive scrub area in the Reserve is located on Shell Island Road, but a large section of rosemary scrub and mixed oak can be found inland from Sand Hill Creek.

The overstory is dominated by a mix of scrub oaks (*Quercus geminata, Q. myrtifolia, Q. chapmanii*) and/or rosemary bushes (*Ceratiola ericoides*). There is usually a dense understory of gallberry (*Ilex glabra*), staggerbush or rusty lyonia (*Lyonia fruticosa*), saw palmetto (*Serenoa repens*), lichens (*Cladonia* spp.) and spike moss (*Selaginella arenicola*). Scrub is less susceptible to invasion by non-natives than other wetter communities.

Fires are infrequent, about one every 20 to 80 years. Frequent fires in oak scrub appear to favor succession towards pine scrub. Fires in rosemary scrubs, on the other hand, tend to leave large, long-term gaps in vegetation.

Pine Scrub

This is actually a subset of scrub, but is differentiated from oak and rosemary scrubs because of different fire regime. The community class includes scrub with sparse pine canopy, scrubby flatwoods with an ecotonal mix of scrub and pine, and the few rockland pine areas found in the Reserve. Higher elevations and well-drained soils characteristic of oak scrubs also define pine scrubs. Several small examples of these communities occur in RBNERR as raised and circular "islands" in the middle of mangrove forests. These are sometimes called xeric flatwoods.

The understory vegetation found in scrub is also found in pine scrub (*Ilex glabra, Lyonia fruticosa, Serenoa repens, Cladonia* spp., *Selaginella arenicola*). Unlike oak scrubs, the dominant canopy is

South Florida slash pine (*Pinus elliottii* var. *densa)* with an oak (*Quercus* spp.) mix.

Fires are frequent, every 3-7 years. Because of the high fire threshold of pine, relative to oak, frequent scrub fires favor succession towards pine scrub.

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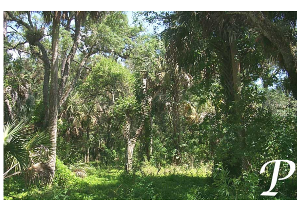

Palm and Oak Hammock

There are about 120 acres of cabbage palm hammocks in RBNERR managed areas. This community is closely associated with pine flatwoods and usually occurs in areas with seasonal ponding or wet depressions. Palm and oak hammocks are a coastal example of temperate broadleafed evergreen forests (Platt and Schwartz 1990).

The dominant overstory species in RBNERR is a mix of cabbage palms (*Sabal palmetto*) and live oak (*Quercus virginiana* var.). The percentage of each tree species varies and the canopy cover ranges from sparse to dense cover. Slash pines (*Pinus elliottii* var. *densa*) are occasionally present, and become dominant in the ecotone between this hammock and surrounding flatwoods. These hammocks are susceptible to incursion by invasive plants, and often have dense patches of Brazilian pepper (*Schinus terebinthifolius*) near disturbed areas such as roads.

Fires are infrequent, about one every 20 to 80 years. More frequent or intense fires appear to favor succession to palm-pine hammocks (Myers 1985).

Tropical Hardwood Hammocks

There are only about 40 acres of tropical hardwood hammocks in the reserve, with the largest single community located on Cannon Island. RBNERR has hammocks on sand and shelly ridges, limestone outcroppings and some shell mounds.

Plants favoring alkaline conditions thrive on these ridges, some natural and some of them enhanced by the Calusa Indians. The dominant canopy species are gumbo limbo (*Bursea simaruba*), live oak (*Quercus virginiana*) and cabbage palm (*Sabal palmetto*). The understory is highly diverse, and epiphytes are well represented. These hammocks have fewer invasive species than other communities, but Brazilian pepper is often found at the perimeter.

These areas are rarely inundated, and have infrequent fires (+26 to 100 years).

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Pine Flatwoods

Pine communities are the dominant upland habitat at Rookery Bay NERR. Both mesic and hydric flatwoods are present in the 1,020 acres within the managed boundary. The dominant canopy is South Florida slash pine (*Pinus elliottii* var. *densa)*, and there are few if any *Quercus* spp. present. The common understory is saw palmetto (*Serenoa repens)*, gallberry (*Ilex glabra),* wax myrtle (*Myrica cerifera),* and wiregrass (*Aristida* spp.*),* with density and species dependent on level of moisture and fire frequency. Pine flatwoods are susceptible to invasion of non-native species, particularly *Melaleuca quinquenervia* and Brazilian pepper.

This community is characterized by flat topography and poorly drained soils resulting in slow runoff and seasonal inundation. Dry season moisture is dependent upon litter cover and depth to hardpan, with hydric flatwoods occasionally exhibiting a dry surficial layer but saturated conditions just below the ground surface. The elevational difference between this community and adjacent cypress and marsh communities is often 1-2 inches.

Fire frequency ranges from 3 to 7 years. In RBNERR these communities are often found adjacent to mangrove forests.

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Cypress savanna/prairie

South Florida cypress prairies are a subset of scrub-shrub wetlands and include marl prairies. These communities are sometimes called dwarf cypress savannas and are located on limestone outcroppings with a thin soil substrate. The CARL property on the north side of Hwy. 41 is RBNERR's only example of this community, more frequently found further east in the Big Cypress Preserve.

The dominant overstory species is pond cypress (*Taxodium distichum* var. *nutans* or *Taxodium ascendens*), but the canopy is sparse and the unique growth structure is often called hatrack cypress. Vegetation is dominated by herbaceous marsh species, and, in RBNERR, is mostly grasses (*Panicum* spp.) and sedges (*Cyperus* spp.). Overall vegetative diversity is low. All disturbed cypress areas are prone to *Melaleuca quinquenervia* invasion.

Fire is more frequent in this community than other cypress stands, several per year in some cases (Ewel 1990), but because litter accumulation is low, fires are not intense. The hydroperiod is determined almost exclusively by rainfall, and frequent dry periods oxidize litter, preventing peat buildup.

Cypress strand

This community is a forested wetland associated with slow-flowing water on sandy substrates, creating the characteristic winding stream, or strand, landscape pattern. There are about 190 acres of cypress strand in the northwest section of the RBNERR managed areas.

The dominant overstory species is pond cypress (*Taxodium distichum* var. *nutans* or *Taxodium ascendens*), but hardwood species are also present – red maple (*Acer rubrum*) and red bay (*Persea borbonia*). *Thalia geniculata* and *Sagittaria latifolia* are common understory species. Brazilian pepper and *Melaleuca*, invasive non-natives, are frequently found at the perimeter.

Fire is infrequent (20 – 100 year frequency); strands are not considered to be fire dependent habitats. Strands have a connection to the surficial aquifer, and consequently have longer periods of inundation than cypress prairies. They do, however exhibit seasonal water fluctuations.

Cypress dome

This community is a forested wetland associated with depressions and long hydroperiods, creating the characteristic circular or oval landscape pattern, with shorter trees on the perimeter and taller trees in the center, creating the dome shape typical of this system. Often, domes have a center circle with a depressional marsh. There is one cypress dome in the northwest section of the RBNERR managed areas, but without a center marsh.

The dominant overstory species is pond cypress (*Taxodium distichum* var. *nutans* or *Taxodium ascendens*), but hardwood species are also present – red maple (*Acer rubrum*) and red bay (*Persea borbonia*). *Thalia geniculata* and *Sagittaria latifolia* are common understory species and bromeliads are frequent. Brazilian pepper and *Melaleuca*, invasive non-natives, are frequently found at the perimeter.

Fire is infrequent (20 – 100 year frequency); domes are not considered to be fire dependent habitats. Domes have longer periods of inundation than cypress prairies. They do, however exhibit seasonal water fluctuations.

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Freshwater marsh: Flatwood

These herbaceous marshes are adjacent to pine flatwoods, and, in RBNERR, are characterized by maidencane (*Panicum* spp.) and duck potato (*Sagittaria latifolia*). Flatwood marshes usually have a distinct circular shape with abrupt transition to pine and saw palmetto flatwoods. These marshes are inundated 6-9 months a year and fires are infrequent (10 years). Periodic drying is essential to maintenance of these marshes. Impoundment causes root loss and plant dieoff, regardless of water depth. There are a few isolated examples of this community in the northwest section of the RBNERR managed areas and off of County Road 951 – probably less than 100 acres.

Freshwater Marsh: Wet Prairie

These sometimes expansive communities occur adjacent to scrub, pine scrub, flatwoods, and saltmarsh, and make up about 400 acres in RBNERR's northwest managed areas. They are characterized by saw grass (*Cladium jamaicensis),* cattails *(Typhus* spp*.),* and maidencane (*Panicum* spp*.)* in what appears to be large monotypic stands. However, even dense growth of these tall grass-like species supports a high diversity of true grasses, sedges, ferns, vines and deeper water marsh plants. Cattail thrives in areas of excess nutrient runoff. Invasive plants include *Melaleuca quinquenervia* and *Lygodium microphyllum* (Old World climbing fern).

Fires are frequent in the large saw grass prairies in the Everglades to the east of RBNERR, and all wet prairies are dependent upon frequent fires (1 – 7 years) to recycle nutrients. Wet prairies are flooded only about 6 months a year, and the extended dry period, coupled with fire, are crucial to maintaining saw grass stands.

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Development

Residential, agriculture, commercial, golf course and mining land uses are the main development surrounding Rookery Bay NERR. Residential uses include single-family, zero lot-line villas, two to three story apartment, townhouse and condominium buildings and mobile home parks. There are no high-rise condominiums, such as those on the skyline of Marco Island, at this time. The corridors along US Hwy 41 (Tamiami Trail) and SR 951 are a mix of shopping centers, gas stations, automotive repair and junkyards, nurseries, tomato and bell pepper production, motels and restaurants. Two auto repair and junkyard operations are located directly adjacent to marshes at the edge of the Reserve. Sand and gravel are the mined commodities.

Concomitant with development are roads and, in SW Florida, canals for flood protection. Retention ponds are required for all new development by the SFWMD – size and depth determined by amount of impervious surface. These water systems now provide year-round freshwater in an area where freshwater has historically been ephemeral. Many of the retention areas are connected to the larger creek and canal system draining the landscape. All of these developed areas contribute to nutrient and contaminant loading to RBNERR's estuaries via this drainage system, without the historic benefit of filtration provided by the long period required for sheetflow to reach the bays following summer rains. Development also brings ornamental and non-native vegetation, clear cutting and filling of native ecosystems and temporary sediment loading to canals and downstream estuaries.

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Estuarine and Saltwater Systems

Estuaries are the broad ecotone connecting upland and freshwater communities to bays and oceans or gulfs. The width of this area of mixed communities is dependent upon the elevational slope of the coast and the tidal range. The tidal range in this area of the Gulf of Mexico is about 1 meter. RBNERR and surrounding areas have a less than 1 foot per mile slope, and the natural five foot elevation contour is north of US Highway 41, from 3 to 7 miles from the coast. Hwy. 41 was built at an elevation of 5 feet, and in addition to connecting Miami to Naples, it has acted as a saltwater barrier ever since.

The southwest coast of Florida is a low energy coast, rarely experiencing killing frosts. Further, the coastal shelf extends outwards for many miles, creating a shallow basin with numerous calcareous outcroppings. These conditions favor the development of mangroves over saltmarsh, creating the unique maze of mangrove islands making up the Ten Thousand Island area and the barrier islands closing in Rookery Bay.

Saltwater Marsh and Saltflats

Saltmarsh is not as extensive in RBNERR as the rest of the coastal United States, and is almost always intermixed with scattered buttonwood (*Conocarpus erectus*) and other mangrove species, primarily black mangrove (*Avicennia germinans*). The differentiation between high and low is an important mosquito control differentiation, and is based on the usual height of the dominant species, rather than on elevational differences.

High marsh, the more frequent marsh in RBNERR, is dominated by needle rush (*Juncus roemerianus)* with a mix of salt grass (*Distichlus spicata)* and sea purslanes (*Sesuvium* spp.), and is usually found on the backside or inside of mangroves. Low marsh, or cordgrass (*Spartina alterniflora* or *bakeri*), is rare in this area where the ocean edge is dominated by mangroves. Kice Island, bordering the Gulf, has a small patch of *Spartina* on the open water side of the mangroves, and there are scattered patches at the edge of the intercoastal waterway, to the east of Keewaydin Island. A mix of *Spartina*, salt grass and purslanes is present in a few inland areas with tidal influence – along Hwy 951 and in the northwestern section of the Reserve.

Saltflats and saline ponds are infrequent in RBNERR's mangrove areas. Saltflats are characterized by high soil salinities and absence of vascular vegetation. They are, however, populated by macroalgae, microalgae, and bacteria. About ten of RBNERR's salt flats have small, mostly circular saline ponds. These saline ponds are differentiated from other larger open water lagoons in mangroves by the lack of tidal connection or influence, and characterized by low levels of plant litter.

These communities are not fire dependent, and are rarely subject to invasive non-native plant species. However, Brazilian pepper is often found on slightly elevated perimeters of *Juncus* stands.

Research

Published research of the Reserve's saltmarsh habitats is limited to three studies, all conducted in the marshes north of the Lake Marco Shores development (Finan and Finan,1979; Heald, 1981; Neff, 1994). Finan and Finan (1979) described this marsh as being dominated by *Juncus roemerianus*, *Eleocharis cellulose* and *Spartina startinae*. This report included a species list, analysis of species abundance and diversity for macroinvertebrates and standing crop calculations for macrophyton. Heald (1981) reported that exotic plants were largely absent from this marsh system. Heald's report also included a species list and a flood map. Neff (1994) studied fat storage fluctuations in sail fin mollies (*Poecilia latipinna*). Mollies stored fat throughout the year, particularly in the winter, and remobilized it for food and reproduction in the early summer (Neff, 1994).

There has been no research, other than species inventories, completed on the Reserve's saltflats.

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Mangroves

Mangroves are the most extensive vegetated habitat in the RBNERR managed areas – about 36,000 acres. The mangrove forests of the Reserve are comprised of four basic forest types: Fringe Forests, Riverine Forests, Overwash Forests and Basin Forests. These habitat types represent a continuum of tidal inundation and freshwater influence.

The same three mangrove species are present in varying degrees of dominance in these four forest subsets: red mangrove (*Rhizophora mangle)*, black mangrove (*Avicennia germinans)*, and white mangroves (*Languncularia racemosa).* Several ground cover plants are common in mangrove forests, despite the closed canopy: sea purslanes (*Sesuvium* spp.), saltwort (*Batis maritima*), glasswort (*Salicornia virginica*), and ferns (*Acrosticum* spp.). Buttonwood (*Conocarpus erectus*) is often found in white mangrove stands in the northwest section of RBNERR managed areas.

Composition and Structure of Mangrove Forests

Based on peat accumulation rates, mangroves have been in South Florida for approximately 6,500 years (Lugo and Snedaker, 1974). The observations by Shier (1969), within the Ten Thousand Islands region, indicate that Vermetid reefs form the nuclei of most of the outer barrier mangrove islands whereas oyster bars form the nuclei of most of the inner lagoon mangrove islands.

Over time, rising sea level has flooded the backwater mangrove forests and created the current configuration of primary barrier islands and backwater bays (Scholl, 1964). One of the earliest descriptions of the mangrove forests of this region was by Davis (1940) as a result of his research expeditions to the Ten Thousand Islands region. Davis' report provides a description of the physiognomy of the three species of mangrove trees found in this region: *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), and *Laguncularia racemosa* (white mangrove). Davis described these trees as adapted to inhabit loose wet saline soils with periodic submergence by tides and to exhibit different degrees of vivipary (seed maturation before and during dispersal, i.e. propagules). In addition, these trees were all found to have buoyant propagules that can be carried by tides and currents.

<u>Red mangroves</u>, *Rhizophora mangle* (Family Rhizophoraceae), possess stilt, prop or buttress roots and produce the most highly developed viviparous propagules. The prop roots of this species contain small pores called lenticels that are used for gas exchange. The leaves are broad and blunt, pointed at the apex, shiny, deep green above and paler below. The elongated propagules are 25 to 30 centimeters long. Flowering occurs in the spring and early summer (Davis, 1940; Lugo and Snedaker, 1974; Odum et al., 1982).

<u>Black mangroves</u>, *Avicennia germinans* (Family Avicenniaceae), have characteristic breathing organs called pneumatophores extending up out of the ground from the roots. These trees have long horizontal "cable" roots that extend out from the tree only a few inches under the soil surface. The leaves are narrowly elliptic, shiny green above and covered with dense hairs below. The propagules are lima bean-shaped and several centimeters long. The tree flowers in early spring and summer (Davis, 1940; Lugo and Snedaker, 1974; Odum et al., 1982).

<u>White mangroves,</u> *Laguncularia racemosa* (Family Combretaceae), are atypical mangroves in that they have partial vivipary and less visible root adaptations. Similar to the black mangrove, the roots of the white mangrove extend horizontally within inches of the soil surface. The lower trunk of this species contains lenticels. White mangroves can develop aerial roots and a conspicuous abundance of lenticels when growing in strongly reducing, anaerobic sediments (Snedaker, 1990). The leaves are broad, oval and rounded at both ends. The seed is 1-1.5 centimeter and broadest at its apex. Flowering occurs in spring and summer (Davis, 1940; Lugo and Snedaker, 1974; Odum et al., 1982).

Overwash forest

Physiognomy

A habitat dominated by mangrove trees is referred to as a mangrove forest. Mangroves can grow on many types of substrate, including mud, sand, rock and peat, but thrive on mud and fine grain sand that is usually anaerobic (Odum et al., 1982). The mangrove forests of the Reserve are comprised of four basic forest types: Fringe Forests, Riverine Forests, Overwash Forests and Basin Forests. These habitat types represent a continuum of tidal inundation and freshwater influence. The following habitat categories reflect Reserve-specific mangrove physiognomy. These categories are also useful for distinguishing functional similarities and differences of mangrove forest types relative to estuarine nutrient and energy cycles (Lugo and Snedaker, 1974; Odum et al., 1982).

Fringe mangrove forests are comprised of mangroves that fringe the coasts of lagoons, tidal creeks and embayments. These forests are inundated daily by tides and are dominated by red mangroves (Lugo and Snedaker, 1974; Odum et al., 1982).

Riverine forests extend along rivers and creeks that receive significance amounts of terrestrial freshwater input. These forests produce the largest trees and are dominated by red mangroves (Lugo and Snedaker, 1974; Odum et al., 1982).

Overwash forests are islands that are flushed by tides completely and frequently. They are dominated by red mangroves and occasionally contain black and white mangroves. Overwash forests have uniform ground surface elevations slightly above mean sea level (Lugo and Snedaker, 1974; Odum et al., 1982).

Basin mangrove forests are inland to the fringe and riverine forests; these forests are flushed by tides infrequently and are dominated by black and red mangroves. Black mangroves dominate areas with higher soil salinity and sulfide concentrations. At extreme inland locations, basin mangrove forests with the least frequent tidal exchange and most extreme fluctuating soil salinity conditions are usually composed of a mixture of stunted red and black mangroves (Lugo and Snedaker, 1974; Odum et al., 1982).

Black mangrove leaves exhibiting salt excretion (white specks on top of leaves)

Physiological Adaptations/Constraints

Odum et al. (1982) lists four abiotic factors limiting the distribution of mangrove trees: climate (especially temperature), salinity, tidal fluctuation and wave energy. Mangrove trees do not survive prolonged temperatures below 0°C (32°F). Water temperatures greater than 39°C (102°F) can kill the seedlings of black mangroves. Black mangroves are the most cold tolerant, whereas red mangroves are the least cold tolerant (Odum et al., 1982).

Black mangroves are more tolerant to high salinity than white or red mangroves. Red mangroves are limited by salinities in excess of 60 ppt while black and white mangroves show signs of stress when soil salinities exceed 80 ppt. Black and white mangroves appear to tolerate higher salinities if grown in clay versus sand (Odum et al., 1982).

Black and white mangroves are primarily salt excreting species with some ability to exclude salts at the root surface. These trees have salt glands on the leaf surface that allow them to excrete excess salts. This osmoregulatory process involves metabolic energy (Odum et al., 1982).

Red mangrove osmoregulation is primarily a passive process, combining salt exclusion at the root surface with leaf surface transpiration, which drives a "reverse osmosis" process. This species is also known to eliminate excess salt by storing it in their leaves and fruits. Red mangrove trees are also capable of maintaining osmotic equilibrium with the environment by regulating the synthesis and degradation of osmotically active metabolites such as proteins and amino acids. Salt exclusion in mangrove trees may also be supplemented by actively accumulating organic solutes (e.g. proline and mannitol) (Snedaker, 1990).

Tides not only affect sediment salinity concentrations, but also contribute nutrients and oxygen and reduce sediment sulfide concentrations (Odum et al., 1982). Pneumatophores appear to be a more effective mechanism for adapting to anaerobic soils than prop roots, enabling black mangroves to thrive in habitats with infrequent tidal inundation (Lugo, et al. (1975). Furthermore, the influence of tides on soil salinity helps exclude most other vascular plants, thereby reducing competition between mangroves and other plants (Odum et al., 1982).

Mangroves cannot survive along coastlines that are exposed to strong wave action (Snedaker, 1990). Low wave energy favors the accumulation of smaller grained sediments. The most productive mangrove forests develop in estuaries with fine-grained sediments with a high percentage of organic matter (Odum et al., 1982). In the absence of catastrophic events, mangrove systems modify the underlying substrate through peat formation composed of root material and are viewed as shoreline stabilizers (Carlton, 1974).

Propagules sprouting among prop roots - *Rhizophora mangle*

Reproduction/Dispersal

Tides provide a means to disperse propagules. Dispersed propagules recruit and establish best in environments with low wave energy (Snedaker, 1990). Mangrove propagules disperse by water and have obligate dispersal times before germination can occur. This time-period is greater for red mangrove propagules (40 days) than it is for black (14 days) or white (8 days) mangroves. The viability of propagules is estimated to be 35 days for white mangroves, 110 days for black mangroves and in excess of 12 months for red mangroves (Davis, 1940). White and black mangrove propagules are more easily carried into intertidal forests than red mangrove propagules; however, red mangrove propagules are better adapted to recruitment under dense canopy due to greater food reserves (Odum, et al., 1982).

Competition

Davis (1940) was one of the first researchers to conclude that the mangrove tree's adaptation to saline conditions is most likely a response to competition with freshwater marsh species. However, within the intertidal environment, the initial distribution of mangrove trees upon an open substrate appears to be less a response to direct interspecific competition and more associated with the dispersal properties, survivability, herbivory and relative availability of their propagules (Lugo and Snedaker, 1974; Odum et al., 1982; Snedaker, 1990).

As trees reach maturity, competition between mangrove tree species may become more important in controlling zonation. Disturbances (e.g. lighting strikes) can open up the canopy and allow less shade tolerate species, such as white mangroves, to become established. Over the long-term, mangrove zonation appears to be a response to external physical factors, geomorphological, meteorological and geochemical processes, rather than a temporal sequence induced by the plants themselves (Odum et al., 1982; Snedaker, 1990).

Herbivory

Grazers of mangrove leaves include whitetail deer, mangrove tree crabs, snails and various insects including grasshoppers and crickets and larvae of moths and butterflies (Odum et al., 1982; McKee, 1999). The review by Odum et al. (1982) reported grazing estimates of 0 to 18% of the total leaf area. Wood boring isopods, Sphaeroma terebrans, burrow into live prop roots of red mangroves (Rehm and Humm, 1973) but do not appear to cause mortality and may even benefit the tree by stimulating regeneration of new prop roots (Odum et al., 1982).

Species-specific differences in the chemical composition of mangrove leaves and tissue structure affect their overall rate of consumption. Black and white mangrove leaves are consumed faster than red mangrove leaves. Leaves tethered and placed on the forest floor are consumed at rates up to 2% per day (McKee, 1999).


Avicennia germinans with galls

Hurricanes

Catastrophic events, such as hurricanes, have major long-term influences on the distribution and composition of mangrove forests (Twiley et al. (1991). The last direct strike by a major Hurricane to the Reserve was hurricane Donna in 1960. The destruction caused by hurricanes is highly variable in terms of spatial patterns and species affected (Lugo and Snedaker, 1974). Variations in wind speed and direction, topography, height of the storm surge, and type and size of the existing vegetation results in different spatial patterns of forest damage. Forest biomass is inversely correlated to frequency of hurricanes. In general, in South Florida, mangrove forests are adapted to rapid growth following hurricane disturbance and are capable of achieving steady state conditions in the period between hurricanes (Lugo et al., 1973)

Twilley et al. (1991) described long-term changes in the Reserve's basin forest structure one and two decades after Hurricane Donna in 1960. Estimates of tree mortally following this event were 25 to 90%, with the highest mortality for trees inhabiting the lowest topography (Lugo and Snedaker, 1974). Within the same habitat, white mangroves were found to be the least susceptible, followed by red mangroves, with black mangrove being the most susceptible. Overall, compared to ten years post hurricane, the forest structure twenty years post-hurricane was described as having decreased tree density, fewer trees in the smaller size classes, a greater number of trees in the larger size classes and a trend to become less black mangrove dominated toward a mixed black and red mangrove forest (Twiley et al. (1991). Based on these observations, and additional data on tree mortality, growth rates and above ground wood production, Twilley et al. (1991) hypothesized that basin forests, within the Reserve, may develop to maturity in twenty-five years.

In the aftermath Hurricane Andrew, a major hurricane in 1992, mature canopy trees suffered the greatest damage (Doyle et al., In Review). In forests exposed to moderate wind damage, larger trees grew faster than small trees (Nalley et al., 1997). Under similar wind conditions, white mangrove trees suffered more storm damage than black or red mangrove trees (Doyle et al., In Review).

Stress Factors and Diseases

Overall, the ability to detect the effects of stress on mangrove forests depends upon the rapidity of the environmental disturbance and the temporal and spatial scale of monitoring effort. Rapid changes in factors such as siltation rates or hydroperiod often lead to obvious increases in mortality. Gradual stress usually results in less dramatic changes and over time, may shift in species composition to one better adapted to the new conditions. In the case of an extreme disturbance, such as the drainage of mangrove forests followed by tree cutting, the event may alter soil chemistry and preclude natural regeneration (Lugo and Snedaker, 1974). The same structures that allow mangroves to grow in anaerobic soil, lenticels and pneumatophores, also make them susceptible to damage from water high in fine suspended material or to flooding associated with stormwater runoff (Odum et al., 1982).

Mangrove distribution can also be gradually affected by rising sea level and land subsidence (Lynch, 1989). In order for a mangrove forest to be maintained at a specific location, the vertical accretion rate of sediments must be greater than or equal to the increase in surface water depths resulting from land subsidence and sea level rise. Measurements of the sediment accretion rates in a basin mangrove forest of Rookery Bay indicated that the forest floor is currently maintaining position relative to surface water depth (Lynch, 1989). Organic matter accounted for nearly 60% of the measured sediment accretion within this forest (Lynch et al., 1989). Processes that reduce the rate of organic matter accumulation could have a significant adverse impact on mangrove forest survival.

The affects of herbicide runoff into mangrove systems can also be another stress factor (Lugo and Snedaker, 1974). Besides the loss of habitat, herbicide damage converts living material into organic debris, which may be decomposed in situ or exported. Recovery from herbicide application varies with the amount of damage and may be in excess of twenty years. Propagule availability and seedling sensitivity to residual herbicide concentrations are two important factors affecting the rate of forest recovery (Lugo and Snedaker, 1974).

There are several pathogenic fungi known to infect mangroves, which are likely to occur within the Reserve. *Phyllosticta hibiscina* and *Nigrospora sphaerica* are found associated with black mangroves. *Cylinrocarpon didymum* forms galls on red mangroves. High incidence of gall formation is associated with forest defoliation (Lugo and Snedaker, 1974).

Mangrove Forest Function

Mangrove forests occupy an interface coupling both organic matter and energy between terrestrial and estuarine ecosystems. Odum et al. (1982) listed twenty factors that influence mangrove productivity (Table 1). In general, mangroves appeared to be more productive than seagrass, marsh grass and most other coastal systems. The most important pathway for transferring mangrove forest productivity to other trophic levels was via the mangrove leaf-detritus pathway (Lugo and Snedaker, 1974). The dissolved organic matter (DOM) and particulate organic matter (POM) derived from this pathway becomes an important contributor to estuarine secondary productivity (Twilley, 1982). Heald (1975) also emphasized the importance of the black mangrove forest detritus in supporting the “mosquito food chain” that provides food for fishes which are, in turn, an important food source for wading birds. Changes in the quantity and quality of freshwater inflow, estuarine circulation, and tidal flushing that alter hydroperiod and salinity patterns result in subtle decreases in the contribution of mangrove forests productivity to adjacent habitats (Lugo and Snedaker, 1974).

Most studies of the mangrove forest productivity conducted within the Reserve have focused on influence of age, species composition, tidal flushing and time since last severe hurricane. The work of Twilley (1988) suggested that the mangrove forests of the Reserve have obtained a level of successional “maturity” with very little change in species composition, an increase in net productivity as measured by wood and forest structure and nearly constant leaf litterfall over a sixteen year period.

Lugo et al. (1975) studied the function and role of mangroves by measuring carbon dioxide exchange and respiration for all three species of mangroves. Overall, they found that the net daytime photosynthetic rate of red mangrove leaves was greater than that of black mangrove leaves, which was greater than that of white mangrove leaves. However, within each forest type, the leaves of the dominant species exhibited the highest net photosynthetic rate (Lugo et al., 1975). Net primary productivity also decreased as salinity increased, perhaps due to the metabolic costs associated with osmoregulation (Lugo and Snedaker, 1974).

In general, gross photosynthesis and transpiration rates were highest in the fringe forests and decrease inland (Lugo et al., 1975). The greatest rate of metabolism occurred in riverine forests where terrestrial runoff and tidal flushing is high. Fringe and basin forests within Rookery Bay were found to have a gross photosynthesis to total respiration (P/R) ratio of > 1 indicating that these systems are net exporters of organic matter (Lugo and Snedaker, 1974). The P/R ratios for fringe forests were generally greater than those for basin forest.

Twilley (1982) estimated that 83% of the total allochthonous organic matter input to the estuarine environments of the Reserve was accounted for by mangrove fringe and basin forests. He also estimated that fringe and basin mangrove forests accounted for approximately 18% of the total (allochthonous + autochthonous) organic carbon available for secondary productivity in the adjacent estuary. Leaf liter turnover rates, due to litter export, are greatest in the overwashed forests, followed by the fringe forests and finally the basin forests (Twilley, 1988). Although the carbon exported per unit area by the basin forests is approximately half that exported by the fringe forests, the basin forests' greater spatial coverage balances the contribution.

Tidal flushing is an important factor influencing the transport of organic matter and nutrients from mangrove forests to the adjacent habitats (Twilley, 1988). Forests with greater tidal flushing have lower sediment nutrient levels and transport more particulate organic matter (POM) from leaves to adjacent bays (Twilley, 1988). POM primarily from leaves is exported out by tides and decomposed by microorganisms, which utilize plant carbohydrates as an energy source (Snedaker, 1990). Larger marine organisms, in turn, consume these microorganisms (Odum, et al., 1982). Under tidal flushed conditions, approximately 50% of the particulate detrital materials produced annually may be exported to adjacent bays (Heald, 1975).

Table 1. Factors influencing mangrove productivity
Species composition
Age
Competing species
Herbivory
Disease
Parasites
Depth of substrate
Nutrient content of substrate
Substrate type
Nutrient content of overlying water
Salinity of soil and overlying water
Transport efficiency of oxygen to the root system
Tidal flushing
Wave energy
Nesting birds
Periodicity of severe stress (hurricanes, herbicides, fire etc.)
Time since last severe stress
Pore water characteristics
Toxic compounds or nutrients from human sources
Human influences on hydrology: diking, ditching, and altering patterns of runoff

Leaf material collected from fringe and overwashed forests had the greatest carbon to nitrogen (C:N) ratio and lowest nitrogen content (Twilley, 1988). Sediment chemistry also followed this pattern. Leaf litter decomposition rates increased inland, corresponding to lower C:N ratios (Twilley, 1988). These results were not only due to decreased liter turnover in forests flushed infrequently by tides, but are also due to species-specific differences in leaf chemical composition. Under similar conditions, the decomposition rate of leaves was greatest for red mangroves followed by white mangroves and then black mangroves (McKee, 1999). Red Mangroves has been shown to have the ability to conserve nitrogen by recovering this nutrient form senescing leaves and stems prior to leaf-fall, thereby producing a litterfall with higher C:N ratios than the other species (Twilley, 1988). The rate of decomposition can also be influenced by the availability of oxygen, the type of substrate and the feeding activity of animals and microorganisms (Lugo and Snedaker, 1974).

Basin forests with a mixture of black and red mangroves had higher litter biomass and lower litter turnover rates than basin forests with monospecific stands of black mangrove (Twilley, 1982). Black mangrove litterfall had a higher percent nitrogen concentration, lower C:N ratios and higher decomposition rates than did red mangrove litterfall (Twilley, 1982). In monospecific stands of black mangrove, leaf litter decomposition rates increased with increasing tidal inundation frequency (Twilley et al., 1986). Leaf litter residence times also increased with distance from the coast (Twilley et al., 1986). Within a basin forest of Rookery Bay, the percent organic content and carbon and nitrogen concentrations of the sediments increased with distance inland; however, sediment phosphorous concentrations along the same sampling transect did not differ significantly (Lynch et al., 1989).

Seasonal patterns in litterfall rates have been recorded for the Reserve. Lowest litterfall rates occurred during the winter and litter standing crop showed little seasonal pattern (Twilley 1988). The litterfall peak for the Reserve was reported to be in the late summer and early fall (Twilley, 1982). During times of peak litterfall, mixed basin forests had greater litterfall rates than monospecific stands. In contrast, no significant differences between these forest types were found during the winter months (Twilley, 1982).

Comparing the organic carbon exchange for two basin mangrove forests, Twilley (1985) found seasonal patterns, with greater export occurring from August to October and the lowest export occurring from December to May. Total carbon export increased following flood tides and peak concentrations were positively correlated with rainfall. Net carbon export was similar for the two basins, although the basin-specific concentration of organic carbon on any given date may have been different. Monthly net carbon export is proportional to the cumulative tidal amplitude (Twilley, 1985). The export of large amounts of organic matter into the estuary was accompanied by a lowering of estuarine photosynthetic rates and an increase in respiration rates, thereby lowering oxygen concentrations of the receiving water (Lugo and Snedaker, 1974).

For basin forests within the Reserve, dissolved organic carbon (DOC) was estimated to be 75% of the total organic carbon export and represented approximately 20% of total leaf litter production (Twilley, 1985). DOC was thought to result from leaching of soluble organic carbon from mangrove leaves and other plant surfaces, such as branches and bark, and from the decomposition of reduced organic matter in the sediments (Snedaker, 1990). Similar to POC, peak export of DOC from basin forests occurred in the fall (Twilley 1982).

Canals though mangrove forests can “short circuit” this export process by shunting overland freshwater sheetflow directly to the estuary (Lugo and Snedaker, 1974). In contrast, natural drainage patterns allow the mangroves to intercept the runoff and redistribute nutrient and organic matter throughout the mangrove forest and adjacent estuarine habitats (Lugo and Snedaker, 1974).

Furthermore, Twilley (1982) cautions that measurements of export that exclude catastrophic storm events underestimate the long-term magnitude of exchange between intertidal wetlands and coastal waters.

Nutrient Cycling

Mangrove systems are dependent on nutrient inputs from terrestrial sources, decomposition within the forest, and inputs from the sea. However, these sources combined do not seem to be enough to maintain the observed rates of metabolism in mangrove systems (Lugo et al., 1973). This is primarily due to the loss of nutrients in the detritus exported to the adjacent estuarine water and suggests that there must be selective pressure for mechanisms of recycling within mangrove forests (Lugo et al., 1973).

In general, mangrove forests are thought to act as a sink for various elements (Snedaker, 1990). Typically, the surface waters associated with mangroves have wide range of salinities (0 to 40 ppt), low macronutrient content (particularly phosphorous), relatively low oxygen content, high total organic carbon and increased color and turbidity (Odum et al., 1982). Tidal water flowing through a mangrove forest lost 10 to 100% of its nitrogen and phosphorous (Lugo and Snedaker, 1974). Nutrients and oxygen are consumed by a combination of periphyton, small invertebrates, mangrove roots, bacteria, fungi and algae associated with the mangrove prop roots and the forest sediments (Odum et al., 1982).

The relative contribution of export and decomposition to litter dynamics and nutrient recycling varies along a tidal gradient (Twilley, 1982). As tidal inundation frequency decreases, the litter dynamics are influenced more by the decomposition and respiration characteristics of the forest floor than by export. With less tidal inundation, organic matter and nutrients become immobilized during litter decomposition and peat deposition (Twilley, 1982).

Mangrove Forests and Estuarine Secondary Productivity

Several researchers have attempted to examine the contribution of the Reserve's mangrove-based detritus to secondary productivity of the adjacent estuary. The nitrogen concentration and nutritional content of leaves increase during decomposition due to colonization by microorganisms (Twilley, 1982). These microorganisms in turn serve as a food source for high trophic level consumers (Odum et al., 1982). McKee (1999) estimated that approximately 50% of the leaf organic carbon deposited on the ground of a basin forest study site at Rookery Bay was processed by invertebrates.

Most sport and commercial species of South Florida appeared to be linked to food chains originating from mangrove detritus (Lugo and Snedaker, 1974). Many of these organisms inhabit mangrove estuarine areas during early stages of their life cycles where they may derive a refuge from predators as well as food. Zieman et al. (1984) examined stable isotope and amino acid signatures of various sources of organic matter during decomposition. These researchers found that within the Reserve the d^{13} C of pink shrimp indicated a stronger contribution from a mangrove-epiphyte-macroalgae complex than from a seagrass origin. Sheridan (1992), found during a survey of the macrofauna within seagrass, open water and fringe mangrove forest habitats of Rookery Bay, that twelve fish and eight crustacean species were caught more often in mangrove habitats. Total benthic population densities in mangroves also exceeded those in adjacent seagrasses and non-vegetated mud (Sheridan, 1997). Annelids and tanaids inhabiting sediments within a mangrove fringe forests were found to exceed

30,000 m^{-2} (Sheridan, 1997). These benthic population densities are equal to or greater than those found in highly productive seagrass habitats elsewhere in the southeastern United States. Sheridan (1997) concluded that red mangroves appear capable of providing high densities of small prey items for mobile estuarine consumers.

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Islands

Rookery Bay NERR is located at the northern edge of the Ten Thousand Islands. The Ten Thousand Islands Aquatic Preserve is managed by RBNERR staff and about 9000 of the islands fall into the Preserve boundaries. The remaining area is managed as part of the Everglades National Park. Some of these 9000 islands fall under joint management responsibility with the U.S. Fish and Wildlife Service Ten Thousand Islands Wildlife Refuge.

Most of these islands are mangrove overwash islands: mangroves rooted on deep substrates of peat and sediment built up over vermetid reefs. Some of the islands have higher central shell and limestone ridges supporting coastal strand and other upland communities. A few along the outer edge facing the Gulf of Mexico have narrow sandy beaches and low dunes.

During summer months, mosquito populations pulse and feed on boaters many feet from island edges even during the day. Consequently, recreational use of the islands is much lower at this time.

Research

Vegetative species and communities have been extensively inventoried on islands surrounding Rookery Bay having beach, dune or upland communities (see species lists). Most of these communities are xeric or mesic with the exception of mangroves on the baysides (Burch 1998, Burch 1996, Craig 1991). There has been little research into productivity or system dynamics, again with the exception of the mangroves and changing shorelines. A study on dune systems is currently in progress (2001-2002), conducted by a RBNERR Research Fellowship recipient.

One species of interest is the Florida thatch palm, Thrinax radiata, previously thought to be extinct on the southwest Florida coast. A small healthy patch has been found on Key Island, on Reserve property. Several islands have coastal scrub communities characterized by cabbage palms and several threatened and endangered cactus. These communities are not found on the mainland.

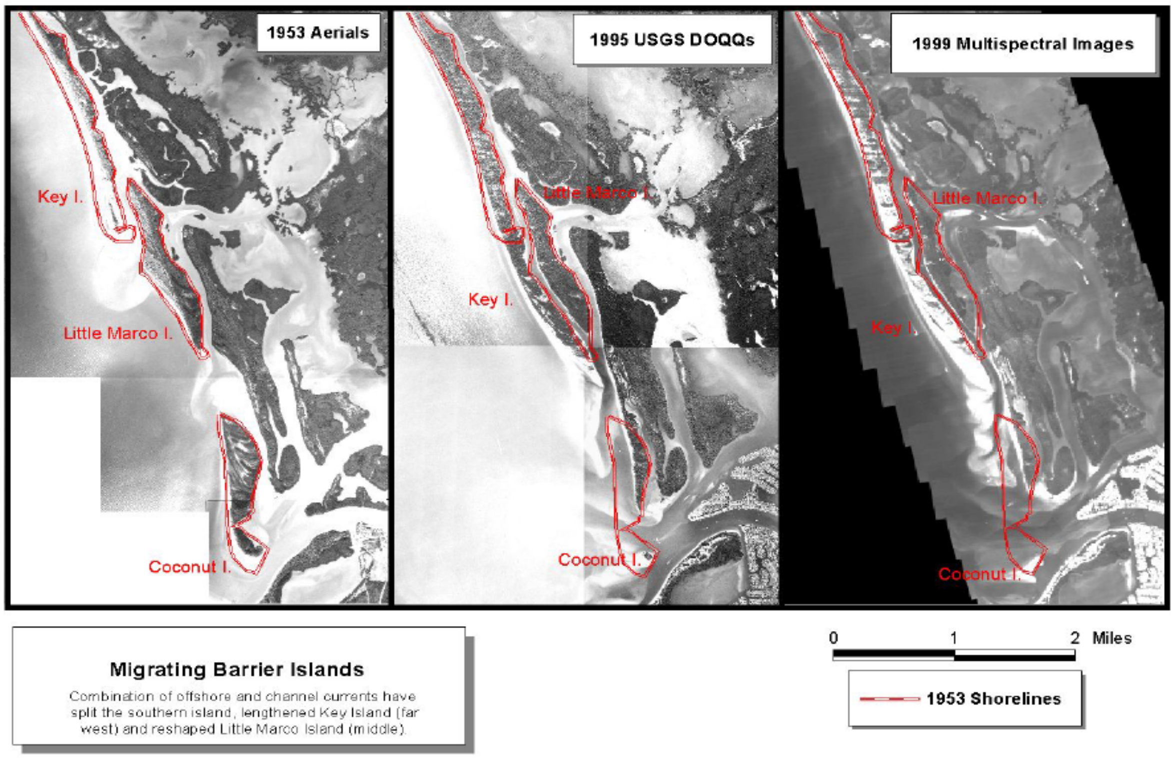
A long term study of shoreline changes on Florida's sandy beaches has been conducted by the University of Florida's Coastal Engineering group (Dean et al. 1998). Collier County is included in the study, and markers 90 through 127 are used to measure landward and seaward migration on shorelines between Gordon Pass and Big Marco Pass, with each marker about 0.2 miles apart. Between 1971 and 1998, the greatest changes are evident in areas of channel dredging – Gordon Pass and Big Marco Pass. The rate of change at Gordon Pass is 15.1 ft/yr and 21.2 ft/yr at Big Marco. The range of change, not including these channeled areas, is from 0.7 ft/yr to 8.9 ft/yr.

Beach/Dune

This universally recognized ecosystem is characterized by areas of shifting sand and beach grasses. There are a few areas with sea oats (*Uniola paniculata)*, but the more common ground covers in the

RBNERR managed areas are sea purslane (*Sesuvium maritima)*, sandspurs (*Cenchrus* spp.), spurges (*Chamaesyce* spp.) and morning glory vine (*Ipomoea pes-caprae*). Fire in this area is rare, and this habitat is not considered fire dependent.

Wide sandy beach areas are not as common in the Reserve or Aquatic Preserve areas as on the east coast due to differing energy intensities from wave action. The southwest Florida coast is a low energy environment, favoring larger, more permanent stands of vegetation. The few areas of existing beach are almost all on outlying barrier islands and are subject to constant migration from offshore and channel currents, as well as from downstream affects of dredging and built structures such as jetties and sea walls.



Coastal Strand

This xeric area behind dunes, with low growth (stunted) forms, is not present in all RBNERR island areas. Many beach areas are short intermittent stretches that transition directly into mangrove forests without a dune or strand area. Some large and notable coastal strand communities can be found on Shell Key, Four Brothers Key, Dismal Key, and Fakahatchee. This community is characterized by sandy, raised elevations with a mix of cactuses, dune plants and an occasional gumbo limbo. Cactuses are a dominant feature (*Cereus pentagonus* and, *Opuntia* spp.), with sea grapes (*Coccoloba uvifera)* and nickerbean (*Caesalpinnia bonduc)* as other common plants. Fire is infrequent (20-80 years). These areas are particularly susceptible to non-native lather leaf invasions.

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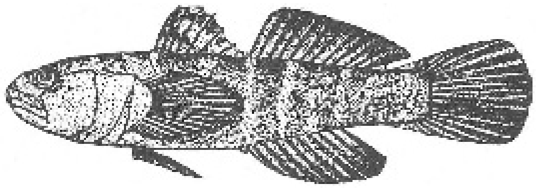


M arine

About 64% of the area managed by RBNERR (both Reserve and Aquatic Preserves) is marine habitat – open water and benthic. Most of this managed area is less than 3 feet in depth, with tidal ranges from –0.3 ft to 4.1 ft. Next to mangroves, fish populations in this marine environment are the most studied resource in the Reserve, with about 100 species present throughout the Aquatic Preserve. Consolidated substrates in RBNERR managed areas support oysters, worm reefs, seagrass and sponge beds, with over 130 species of benthic invertebrates identified. Unconsolidated substrates are often covered with macroalgae mats. Current research by RBNERR focuses on water quality, fish and crab populations, seagrass location and density and bathymetric mapping.

Top left: oyster reef
Top right: worm tube
Bottom: tubes in ground

B enthic Habitat

Oyster reefs, seagrasses, unconsolidated substrates and macroalgae mats are the predominant benthic habitat throughout the bays and backwaters of both the Reserve and the Aquatic Preserves. Sponge beds and worm reefs are evident, but the extent and locations of coverage are not documented. Anecdotal information about historic seagrass beds exist, but many of these areas are now mud bottom.

Benthic research

Thoemke and Gyorkos (1988) studied the distribution and abundance of benthic invertebrates in Rookery Bay, Hall Bay and Henderson Creek for one-year from December 1984 to November 1985. Samples consisted of the top unconsolidated portion of eight 7.62 cm diameter cores. The researchers collected 129 species including sixty-five species of polychaetes, thirty-four species of crustaceans and twenty-four species of mollusks. Polychaetes and mollusks were found to dominate this collection. Two peaks in infaunal abundance occurred, one in April (due to polychaetes and mollusks) and one in June (due to crustaceans). Species diversity peaked in May and declined thereafter. Infaunal densities ranged from 1,042 to 11,664 individuals per square meter in April and October respectively. Based on the species composition of this collection, compared to sites with documented eutrophication, the researchers concluded that there was no evidence to suggest that the Reserve was experiencing nutrient enrichment.

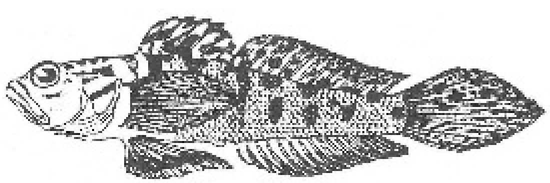
Sheridan (1997) compared benthic infaunal abundances within intertidal habitats including red mangrove forests, seagrass beds and non-vegetated mud. The infauna of seagrass and non-vegetated mud habitats was found to be more diverse than that of the mangrove habitat. However, total densities were always higher in the mangrove habitat, reaching a maximum of 52,914 organisms per square meter. In this study, tanaids and annelids were the numerical dominants. In a survey of benthic infauna of shoal grass habitats of Johnson Bay, Devlin et al. (1988) found polychaetes and amphipods to dominate. The maximum density of the infauna reported in this latter study was 65,902 organisms per square meter.

The Ten Thousand Islands and the estuaries around Marco Island were, at one time, the most productive and extensive southern quahog (*Mercenaria campechiensis*) harvesting area in the United States (Godcharles et al., 1973). Harvesting began in 1880 and declined in 1947, coincidental with an outbreak of red tide (Godcharles et al., 1973). In 1973, Godcharles et al. used a commercial hydraulic dredge, similar to the equipment used previously in this fishery, to survey quahogs within historic clam beds. This sampling effort produced low and variable densities of quahogs.

Seagrass

The primary seagrasses for the region managed by the Reserve are *Halodule wrightii* (shoal weed), *Halophila englemanni* (star grass), *Syringodium filiforme* (manatee grass) and *Thalassia testudinum* (turtle grass) (Nalley et al.,1997). Other attached submerged vegetation include the algal species *Caulerpa verticillata*, *Caulerpa sertularoides* and *Acanthophora spicifera* (Nalley et al., 1997). Accurate aerial seagrass surveys in the area managed by the Reserve are limited to coastal water habitats because low visibility of backwater estuarine water limits the usefulness of large-scale aerial surveys (Collier County Environmental Services Division, 1991).

Most data regarding the occurrence of seagrass in backwater estuaries in the region has been obtained through records of bycatch associated with bottom trawls (Yokel, 1975; Colby et al., 1985). These data indicate that some loss of seagrass habitat has occurred. Research conducted by Carter et al. (1973) in 1972 described Fakahatchee Bay as having dense stands of turtle grass and shoal weed. Similarly, in a study conducted in 1971 and 1972, Yokel (1975) described the western section of Fakahatchee Bay as having dense sands of shoal weed, with light to moderate quantities of turtle grass. Ten years later, Colby et al., (1985) recorded bycatch data from trawls in Faka Union Bay, Fakahatchee Bay, Buttonwood Bay, Sugar Bay, West Passage Bay, Palm Bay, Pumpkin Bay, Lane Cove and Chokoloskee Bay and found that 97% of the samples contained little or no seagrass. Browder et al. (1986) also reported little or no seagrass in Fakahatchee Bay during studies conducted in 1984 and 1985.



Several researchers analyzed species abundance and percent coverage for various locations and depths (Banks, 1975; Nalley et al.,1997). In general, shoal weed tends to dominate in water with depths between 0.3 and 0.6 meters, whereas star grass dominance begins at one meter and continues to approximately 1.5 meters (Banks, 1975). This relationship tends to be more pronounced in backwater locations (Nalley, et al., 1997). Banks (1975) reported finding turtle grass in coastal areas from low tide to 10 meters. However, recent surveys by the Reserve's staff indicated that coastal seagrass habitats in the vicinity of Cape Romano do not occur beyond depths of two meters (Ryder, personal observation).

Zieman et al. (1984) studied the relative role of seagrass and mangroves in estuarine food webs using stable isotope and amino acid racemization techniques. These data suggested that a different mode of decomposition exists for seagrasses than for mangroves when decaying under similar conditions. In this study, the carbon source for pink shrimp collected from a mangrove dominated estuary, Rookery Bay, more closely matched a mangrove-epiphyte-macroalgae complex than a seagrass carbon source.

Macroalgae

Macroalgae is a frequent bycatch reported by trawl studies in the area (Carter et al. 1973; Yokel, 1975). Carter et al. (1973) used respirometers to estimate primary productivity of benthic plant communities dominated by macroalgae and found the productivity of these habitats to be similar to those dominated by seagrass. Uranowski (1996) studied the seasonal biomass, productivity and community composition of macroalgae in the fringe mangrove forests of the Reserve. The algae assemblage was dominated by the red algae, *Bostrychia scorpioides*, followed by the green algae *Boodleopsis pusilla*. Twenty-two other algal species, including nine chlorophyta and thirteen rhodophyta were also recorded. The rate of carbon fixation by these macroalgae was reported to be 0.22 to 0.93 g Cm-2/day with the greatest rates occurring in the spring (Uranowski, 1996).

Oyster reef

Shirley and Haner (1997) studied the population dynamics of crabs on oyster reef habitats in Henderson Creek and Blackwater River from May 1996 to April 1997 relative to salinity fluctuations. Recruitment of juvenile porcellanid (stenohaline) and xanthid (euryhaline) crabs to both estuaries was found to be similar, peaking in the early wet season. In contrast, these researchers found significantly fewer adult stenohaline crabs in Henderson Creek. Site-specific differences in salinity fluctuations were also observed. This study concluded that the altered freshwater inflow into Henderson Creek was adversely affecting stenohaline crab populations. The Reserve staff continues to monitor crab populations on oyster reefs within Henderson Creek and Blackwater River and has expanded this study to include Fakahatchee Bay and Faka Union Bay.

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Open Water

Rookery Bay NERR and the Cape Romano – Ten Thousand Islands Aquatic Preserves cover a total of about 110,000 acres, 68,300 acres in open water. Beyond the channels maintained for navigation, much of these waters are shallow, and support a high diversity of fish, plankton and invertebrates.

Beginning in 1999, the Reserve staff has conducted ongoing otter trawl collections in Fakahatchee Bay, Faka Union Bay and Pumpkin Bay. A Henderson Creek collection began in 2000. The purpose of this ongoing study will be to monitor the changes in fish populations in association with watershed hydrological restoration projects underway in the Henderson Creek and Ten Thousand Islands watersheds. In addition, data being collected at the Reserve's continuous water quality monitoring stations will be used to assess the effects of physicochemical conditions on fish populations.

Research
<u>*Fish and Pelagic Macroinvertebrates*</u>
<u>*Plankton*</u>
<u>*System Networks (Food webs)*</u>

Fish and Pelagic Macroinvertebrates
Most information concerning the Reserve's fish populations comes from trawl studies. Unfortunately, due to differences in methodology and locations, direct comparisons of these studies are problematic. The earliest record of trawl data for the area managed by the Reserve comes from Yokel (1975a,1982). Yokel conducted a two-year night-time otter trawl study from June 1970 to July 1972 within Rookery Bay and Henderson Creek. In this study, 728 trawls collected 25,790 fish representing 64 species with the top six species being, in order of abundance, pinfish (*Lagodon rhomboides*), silver jenny (*Eucinostomus gula*), pigfish (*Orthopristis chrysoptera*), silver perch (*Bairdiella chrysoura*), spotfin mojarra (*Eucinostomus argenteus*) and lane snapper (*Lutjanus synagris*). Yokel also found that fish and pink shrimp (*Penaeus duorarum*) abundances peaked during the summer. Henderson Creek had the highest species diversity of the locations sampled. Yokel (1975b) also conducted a one year night-time otter trawl study (July 1971 to July 1972) to compare animal abundances in similar habitats in Rookery Bay, near Marco Island and in Fakahatchee Bay. In this study, 819 trawls collected 30,456 fish representing 59 species, with nearly 50% of the total catch coming from Fakahatchee Bay. The top five species collected were pinfish, silver jenny, pigfish, silver perch and lane snapper.

Carter et al. (1973) combined the results of seines, surface trawls and otter trawls and compared fish populations in Faka Union Bay and Fakahatchee Bay. The top six species in order of abundance were *Anchoa* sp. (primarily *mitchilli*), yellowfin menhaden (*Brevoortia smithi*), scaled sardine (*Harengula pensacolae*), pinfish, silver perch and silver jenny. Fakahatchee Bay was found to have a higher diversity and abundance than Faka Union Bay. During their study, Carter et al. (1973) collected 273,270 fishes representing 96 species.

Weinstein et al. (1977) reported collecting 30,051 fish representing 95 species in 2,618 otter trawls conducted over a four year period (June 1971 to August 1975) in McIlvaine Bay, Johnson Bay, Addison Bay and around Marco Island. The top six species in the Weinstein et al. (1977) collection were silver jenny, pinfish, pigfish, spotfin mojarra, lane snapper and code goby (*Gobiosoma robustum*). Weinstein et al. (1973) reported a range of Shannon-Weaver diversity index values of 2.068 to 2.4905 for these bays.

Colby et al (1985) conducted surface and bottom trawls in the Faka Union Bay as well as four Bays to the east and four bays to the west. These collections were made from August 1982 to August 1983. These researchers related species composition, relative abundance, size and food consumed to salinity, sediments and aquatic vegetation. The top six species collected in this study were *Anchoa* sp., spotfin mojarra, silver jenny, black-cheeked tonguefish (*Symphurus plagiusa*), lind sole (*Archirus lineatus*) and sand seatrout (*Cynoscion arenarius*). Anchovy, menhaden, silversides and needle fish were predominately collected with surface trawls and pinfish, pigfish, sand seatrout, and silver perch were more common in otter trawls. This study found numbers and biomass of fish and the numbers of certain macroinvertebrates to be substantially less in Faka Union Bay than the other sampling locations. *Prionotus tribulus*, *Menidia beryllina*, *Opsanus beta* and *Mugil* sp. were collected in all surveys yet never in Faka Union Bay. Also, the reduction in fish densities with the onset of the rainy season was more evident in Faka Union Bay where numbers were reduced by 83% as opposed to 70% in the Bays to the east and 50% in the bays to the west. Spotfin mojarra were collected in disproportionately greater numbers in Faka Union Bay relative to the other sampling locations.

Browder et al. (1986) used surface and otter trawls to collect fish and macroinvertebrates during a monthly study conducted from July 1982 to June 1984. Stations were sampled in Pumpkin Bay, Dismal Pass, Fakahatchee Bay, Fakahatchee Pass, Faka Union Bay and Faka Union Pass. Surface and bottom trawl data were combined. A total of 85,561 fish representing 71 species were collected. Included in this dataset were 882 otter trawls which collected 18,252 fish representing 71 species. The top six most abundant species were the same as those reported by Carter et al. (1973), bay anchovy (primarily *mitchilli*), yellowfin menhaden, scaled sardine, pinfish, silver perch and silver jenny. Browder et al. (1986) found blue crabs (*Callinectes sapidus*) and pink shrimp to be most abundant in Pumpkin Bay. However, seasonal shifts were noted, with winter catches of pink shrimp equal in Pumpkin and Faka Union Bay and less in Fakahatchee Bay. Peak catches of blue crabs were in the winter-spring and peak catches of pink shrimp were in the summer.

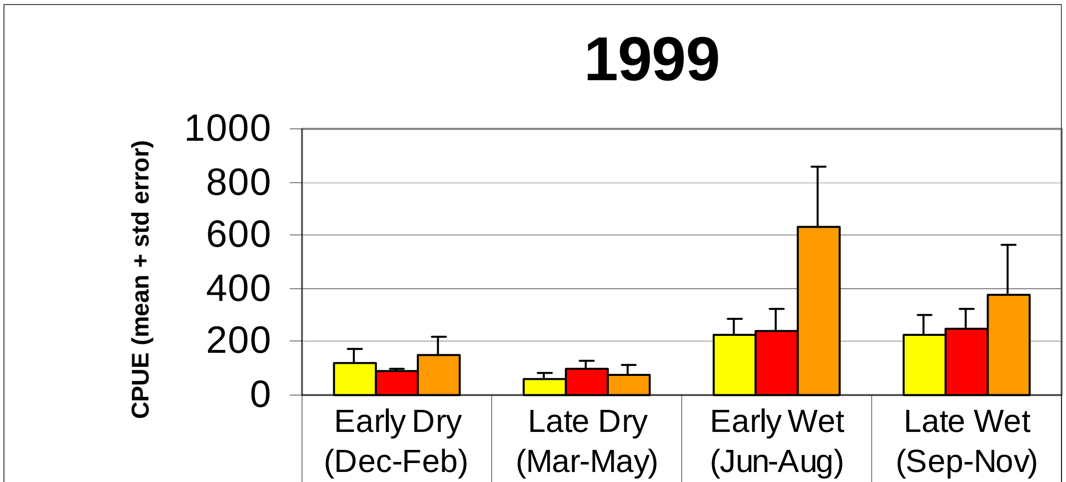
Yokel (1975, 1982) reported the greatest fish abundances from trawls over sites with grass beds in Rookery Bay, Fakahatchee Bay and Near Marco Island. Specifically, the greatest abundances of pinfish, pigfish and pink shrimp were associated with trawling stations in shoal weed (*Halodule wrightii*) habitats. The greatest abundances of silver perch, silver jenny and lane snapper were associated with a trawl station adjacent to a mangrove fringe habitat within a sparse seagrass bed. Spotfin mojarra were collected most often in Henderson Creek, with a bottom habitat described as fine sand with no vegetation. Carter et al. (1973) found pinfish and silver perch in greater abundances in the seagrass beds (described as dense stands of turtle grass (*Thalassia testudinum*) and shoal weed) within Fakahatchee Bay. Similarly, Weinstein et al. (1977) found that fish diversity was greatest in trawls associated with seagrass habitats. Specifically, Weinstein et al. (1977) found pinfish and pigfish to be significantly associated with seagrass beds. In addition, pink shrimp also appear to be associated with seagrass (Weinstein, 1977). Colby et al. (1985) suggested that the effect of altered salinity or benthic habitat availability were not enough to directly explain the reduced fish abundance found in Faka Union Bay, and concluded that the variation in food (benthic fauna) may also influence the observed pattern of fish distribution. In contrast to previous researchers, Colby et al. (1985) reported no seagrass bycatch in 97% of the trawls conducted in the bays of the Ten Thousand Islands, including Fakahatchee Bay. Browder et al. (1986) also reported little or no seagrass in Fakahatchee Bay. Despite this, Browder found Fakahatchee and Pumpkin Bay to have higher species diversity than Faka Union Bay. The results of Browder et al. (1986) differed from those reported by Carter et al. (1973), in that Browder et al. (1986) seldom found the fish abundances in Fakahatchee Bay to be greater than Faka Union Bay.

The Reserve's staff repeated Yokel's study (Yokel, 1975a, 1982), during a one-year (January 1990 to December 1991) night-time otter trawl study using the same locations and the same type of sampling gear (Theberge, unpublished data). During this study, 336 trawls collected 29830 fish representing 77 species. This is greater than twice the catch per unit effort and a more diverse fish assemblage than reported by Yokel (1975a, 1982). In addition, the number of fish collected at each station was similar. The most numerous fish collected were, in order of abundance, spotfin mojarra, pigfish, silver jenny, bay anchovy and pinfish.

Beginning in 1999, the Reserve staff has conducted ongoing otter trawl collections in Fakahatchee

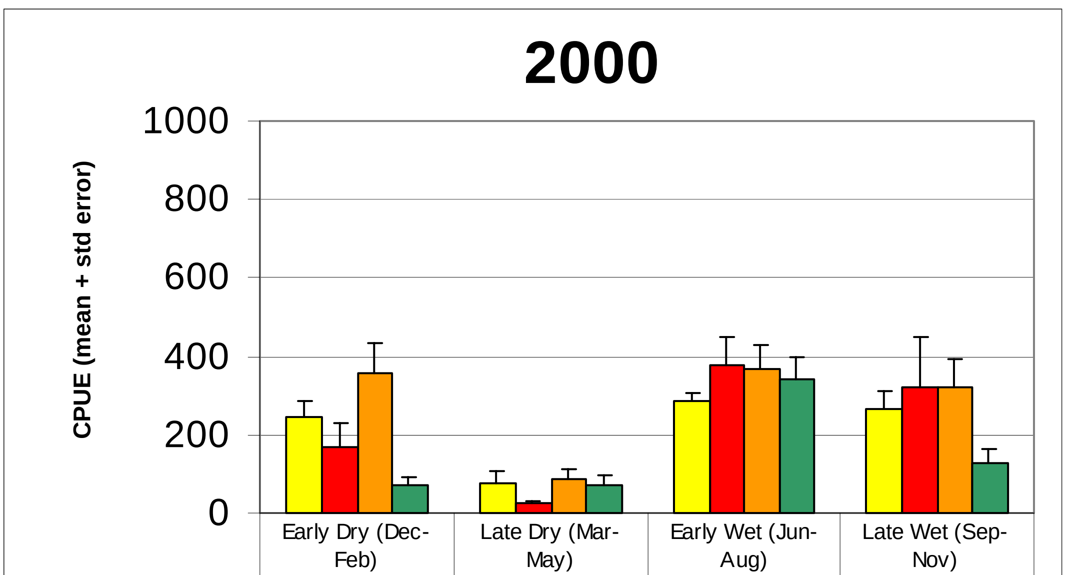
Bay, Faka Union Bay and Pumpkin Bay. A Henderson Creek collection began in 2000. During this time, 264 trawls have collected 32,236 fish representing 57 species, a much higher catch per unit effort, yet a slightly lower diversity, compared to previous studies (O'Donnell, unpublished data). These data also indicate that both season and location influence fish abundance (Figures 1 and 2).

Greater numbers of fish were caught in Pumpkin Bay, especially during the early wet season (June through August) in 1999 and the early dry season (December through February) in 2000. In 2000,



	Early Dry (Dec-Feb)	Late Dry (Mar-May)	Early Wet (Jun-Aug)	Late Wet (Sep-Nov)
Fakahatchee Bay	122	64	225	222
Faka Union Bay	90	97	239	251
Pumpkin Bay	154	76	631	379

Figure 1. Catch per trawl by location and season during 1999.



	Early Dry (Dec-Feb)	Late Dry (Mar-May)	Early Wet (Jun-Aug)	Late Wet (Sep-Nov)
Fakahatchee Bay	245	79	283	264
Faka Union Bay	168	24	376	323
Pumpkin Bay	357	85	365	321
Henderson Creek	71	74	340	129

Figure 2. Catch per trawl by location and season during 2000.

fewer fish were collected in Henderson Creek, especially during the late wet season and early dry season, than in the other three bay systems. In 1999, Pumpkin Bay had the lowest species diversity (H' = 1.527, Shannon-Weaver Index) of the three bays sampled. In 2000, Faka Union Bay had the lowest diversity (H' = 1.405) followed by Henderson Creek (H' = 1.422) then Pumpkin Bay. In both years, Fakahatchee Bay had the greatest diversity (1999 H'= 1.772 and 2000 H' = 1.788).

In both years the peak catch for pink shrimp occurred in the late rainy season. In 2000, significantly fewer pink shrimp were collected in Henderson Creek relative to the other three bay systems. In 1999, peak blue crab abundances were found during the late rainy to early dry season with fewer blue crabs collected in Fakahatchee Bay than in Faka Union Bay or Pumpkin Bay. However, in 2000, the blue crab catch peaked in early to late dry season with fewer crabs collected in Henderson Creek followed by Pumpkin Bay, and greater numbers in Fakahatchee Bay and Faka Union Bay. The most frequently collected fish at all sites during both years and all seasons were the combined catch of spotfin mojarra and silver jenny. The most numerous species caught were found to vary by year, site and season (Tables 1, 2 & 3, listed in order of abundance).

Table 1. Top six species collected by year.

1999	2000
Eucinostomus sp.	*Eucinostomus* sp.
Symphurus Plagiusa	*Anchoa* sp.
Lagodon rhomboides	*Lagodon rhomboides*
Synodus foetens	*Symphurus plagiusa*
Prionotus tribulus	*Synodus foetens*
Sphoeroides nephelus	*Achirus lineatus*

Several researchers have used the size and abundance data collected from trawl studies to infer patterns of recruitment and spawning. Yokel (1975a) reported that silver jenny recruitment occurred in August and September. Weinstein et al. (1977) indicated that silver jenny exhibit a fall spawning cycle, with peak numbers collected beginning at the onset of the dry season until water temperatures dropped markedly. Yokel (1975a) indicated that recruitment by pinfish occurred in December to April with the onset of the rainy season serving as a cue to move offshore to spawn. Weinstein et al. (1977) also reported that pinfish appear to use inshore habitats as a nursery. Pinfish recruitment was reported as beginning in January with a size distribution shift from 11-15 mm to 46-55mm and peak numbers occurred from January to July (Weinstein, et al., 1977). Yokel (1975a) also indicated that silver perch recruitment occurred from March to July with the highest abundance in March through August and lane snapper recruitment occurred between June and October with the highest abundances recorded between June and October.

Pink shrimp in the Ten Thousand Island region are also thought to use these waters as a nursery ground, spending two to six months as juveniles inshore, before contributing to the Sanibel grounds fishery (Costello and Allen, 1986). Yokel (1975a) found that a bimodal peak of recruitment of young

Table 2. Top six species collected by year and location.

1999			
Fakahatchee Bay	**Faka Union Bay**	**Pumpkin Bay**	**Henderson Creek**
Eucinostomus sp.	*Eucinostomus* sp.	*Eucinostomus* sp.	not collected
Lagodon rhomboides	*Lagodon rhomboides*	*Lagodon rhomboides*	
Symphurus plagiusa	*Symphurus plagiusa*	*Symphurus plagiusa*	
Synodus foetens	*Synodus foetens*	*Synodus foetens*	
Prionotus tribulus	*Anchoa* sp.	*Prionotus tribulus*	
Sphoeroides nephelus	*Sphoeroides nephelus*	*Sphoeroides nephelus*	
2000			
Fakahatchee Bay	**Faka Union Bay**	**Pumpkin Bay**	**Henderson Creek**
Eucinostomus sp.	*Eucinostomus* sp.	*Eucinostomus* sp.	*Eucinostomus* sp.
Lagodon rhomboides	*Symphurus plagiusa*	*Anchoa* sp.	*Lagodon rhomboides*
Symphurus plagiusa	*Lagodon rhomboides*	*Lagodon rhomboides*	*Anchoa* sp.
Synodus foetens	*Anchoa* sp.	*Symphurus plagiusa*	*Synodus foetens*
Anchoa sp.	*Synodus foetens*	*Syngnathus scovelli*	*Lutjanus synagris*
Gobiosoma robustum	*Achirus lineatus*	*Synodus foetens*	*Arius felis*

Table 3. Top six species collected by year and season.

1999			
Early Dry Season	**Late Dry Season**	**Early Wet Season**	**Late Wet Season**
Eucinostomus sp.	Eucinostomus sp.	Eucinostomus sp.	Eucinostomus sp.
Lagodon rhomboides	Lagodon rhomboides	Symphurus plagiusa	Symphurus plagiusa
Symphurus plagiusa	Symphurus plagiusa	Anchoa sp.	Achirus lineatus
Synodus foetens	Orthopristis chrysoptera	Achirus lineatus	Prionotus tribulus
Sphoeroides nephelus	Synodus foetens	Synodus foetens	Gobiosoma robustum
Gobiosoma robustum	Sphoeroides nephelus	Bairdiella chrysoura	Cynoscion arenarius
2000			
Early Dry Season	**Late Dry Season**	**Early Wet Season**	**Late Wet Season**
Eucinostomus sp.	Eucinostomus sp.	Eucinostomus sp.	Eucinostomus sp.
Lagodon rhomboides	Lagodon rhomboides	Lagodon rhomboides	Lutjanus synagris
Anchoa sp.	Anchoa sp.	Lutjanus synagris	Anchoa sp.
Synodus foetens	Synodus foetens	Synodus foetens	Synodus foetens
Symphurus plagiusa	Symphurus plagiusa	Symphurus plagiusa	Symphurus plagiusa
Achirus lineatus	Sphoeroides nephelus	Achirus lineatus	Achirus lineatus

shrimp to Rookery Bay occurred in July to September and January to March. Weinstein et al. (1977) indicated that the net movement of shrimp from inland bays peaked in October with a net influx of juvenile recruits beginning in April with a peak in July.

Plankton

Plankton sampling has also been used to determine spawning cycles and bay-specific larval recruitment patterns. Collins and Finucane (1984) conducted a quarterly ichthyoplankton survey of estuarine waters, including Caxambas Pass, Coon Key Pass, Faka Union Bay, Fakahatchee Pass and Cape Romano, from May 1971 through February 1972. These researchers found the peak number of fish eggs in winter-spring, the peak in fish larvae in spring and summer and the peak in zooplankton (fish larvae food) in the summer. Collins and Finucane (1984) also found that fewer zooplankton, fish eggs and fish larvae were collected from Faka Union Bay than Fakahatchee Pass. Browder (1988) compared the concentration of fish larvae in bayward transport into Fakahatchee Bay versus Faka Union Bay. In general, spring was the peak concentration of all ichthyoplankton. The concentration of fish larvae in bayward transport was nearly twice as great in Fakahatchee Pass as in Faka Union Pass. These studies demonstrated the negative effects of excessive canal discharges associated with the Faka Union Canal on larval fish recruitment. Tolley et al. (1987) reported that summer is the peak spawning period for snook. During a one-year study of Naples Bay, these researchers found that increased larval snook abundance occurred in July during a flood tide within five days of a full moon.

System Networks (Foodwebs)

Trophic relationships of fishes within the estuaries have been the focus of several investigations. Carter et al. (1973) conducted gut analyses of juvenile snook (Centropomus undecimalis). Snook greater than 26mm were found to be primarily piscivorous, snook less than 20 mm were found to be planktivorous and those from 21 to 25 mm were classified as feeding on a mixture of zooplankton, fishes and shrimp. Kinch (1976) conducted gut analyses for fishes collected in the canals of Marco Island. This study found evidence that scaled sardine (21-35mm) food items include copepods, amphipods, mysids and polychaetes with the most important food item for larger fish (35-65mm) being crab zoea. Smaller pinfish (<31mm) gut contents included copepods, oligochaetes, polychaetes and amphipods, whereas the gut contents of larger pinfish (>31mm) were dominated by algae. Smaller (<60mm) spotfin mojarra were found to have eaten polychaetes, oligochaetes, amphipods, copepods, tanaids and nematodes. The gut contents of larger spotfin mojarra (> 60 mm) were found to include mostly polychaetes.   The work of Zieman et al. (1984) indicated that the isotopic composition of the carbon source used by pink shrimp collected from Rookery Bay more closely matched mangrove-epiphyte-macroalgae than seagrass.

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Aquifers and Surface Water

The principle source of drinking water in southwest Collier County is a shallow, or Chokoloskee Aquifer. This aquifer is recharged primarily by rainfall. Most of this formation is underlain by the Tamiami Formation, a thin, highly permeable layer with the top exposed in some areas. The Hawthorne Formation, present in north Collier County, is absent in the Reserve and Aquatic Preserve boundaries. The Floridian Aquifer lies beneath the Tamiami in southwest Collier County and extends out into the coastal shelf. The top of this formation is about 400 ft down at the coast. There are artesian flows from this aquifer in RBNERR areas, but the water is heavily mineralized and therefore not potable. An additional aquifer has recently been identified, and cores from RBNERR watersheds indicate that this gray limestone aquifer is present in the Preserve area.

Aquifers and Surface Water Research

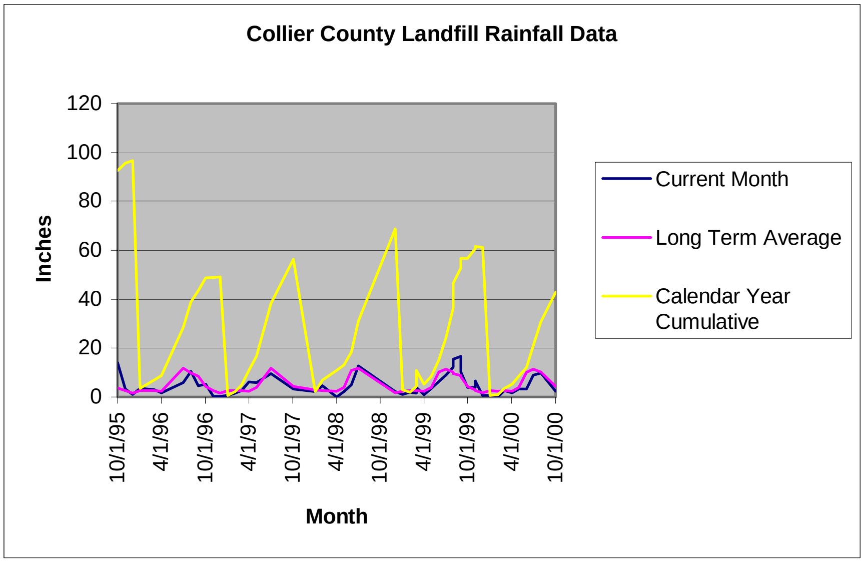
The principle source of drinking water in southwest Collier County is a shallow aquifer , or Chokoloskee Aquifer, extending from 25 to 90 feet in depth (Jarosewich and Wagner 1985). This aquifer is recharged primarily by rainfall. This aquifer is restricted from recharging the lower aquifer in most of the county because of silt, marl and dense, unfractured limestone layers (McCoy 1962). Most of this formation is underlain by the Tamiami Formation, a thin, highly permeable and fossiliferous layer with the top exposed in some areas. The Hawthorne Formation, present in north Collier County, is absent in watersheds and coastal areas in the Reserve and Aquatic Preserve boundaries.

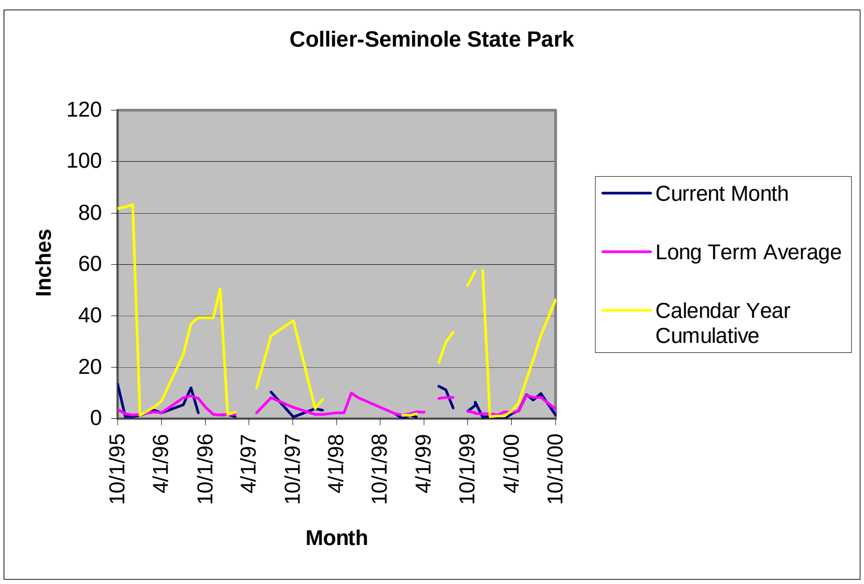
The Floridian Aquifer lies beneath the Tamiami in southwest Collier County and extends out into the coastal shelf. The top of this formation is about 400 ft down at the coast. There are artesian flows from this aquifer in RBNERR areas, but the water is heavily mineralized and therefore not potable. Recharge of this aquifer occurs in areas where the surface of the formation is at or near the surficial water table or where the pieziometric head is below the level of surface water and there is no confining layer. Since the head is about 200 feet throughout south Florida, recharge of this aquifer does not occur outside of the central Florida ridge (McCoy 1962).

An additional aquifer has recently been identified in south Florida that lies between the shallow and Tamiami aquifers. Cores from RBNERR watersheds indicate that this gray limestone aquifer is present in the Preserve area (Edwards et al. 1998). This formation is unnamed, and may be part of the proposed Long Key formation, newly discovered and present in the Florida Keys.

There is some concern over increasing saltwater intrusion into these aquifers (McCoy 1974). A significant increase in the area of mangrove forests has been observed by some researchers, even into areas formerly supporting cypress (Alexander and Crook 1973). In 1974, chloride concentrations in the 951 Canal were as high as 381 mg/l, in excess of the 250mg/l recommended by the National Academy of Science as acceptable upper limits (McCoy 1974). During the same study, the Lely Canal chloride concentration was >500 mg/l. Retention ponds in developments on Marco Island and near the Belle Meade grade exhibit permanent chemical stratification from saltwater intrusion. The Belle Meade grade is an historic trail bed formed by connecting natural ridges with filled sloughs, and is still visible between the eastern shore of Henderson Creek near Shell Island Road and the abandoned agricultural areas to the east of Cnty. Rd. 951 and south of the Fiddler's Creek development. Marshes and groundwater immediately south of the Grade are hypersaline (who? When?).

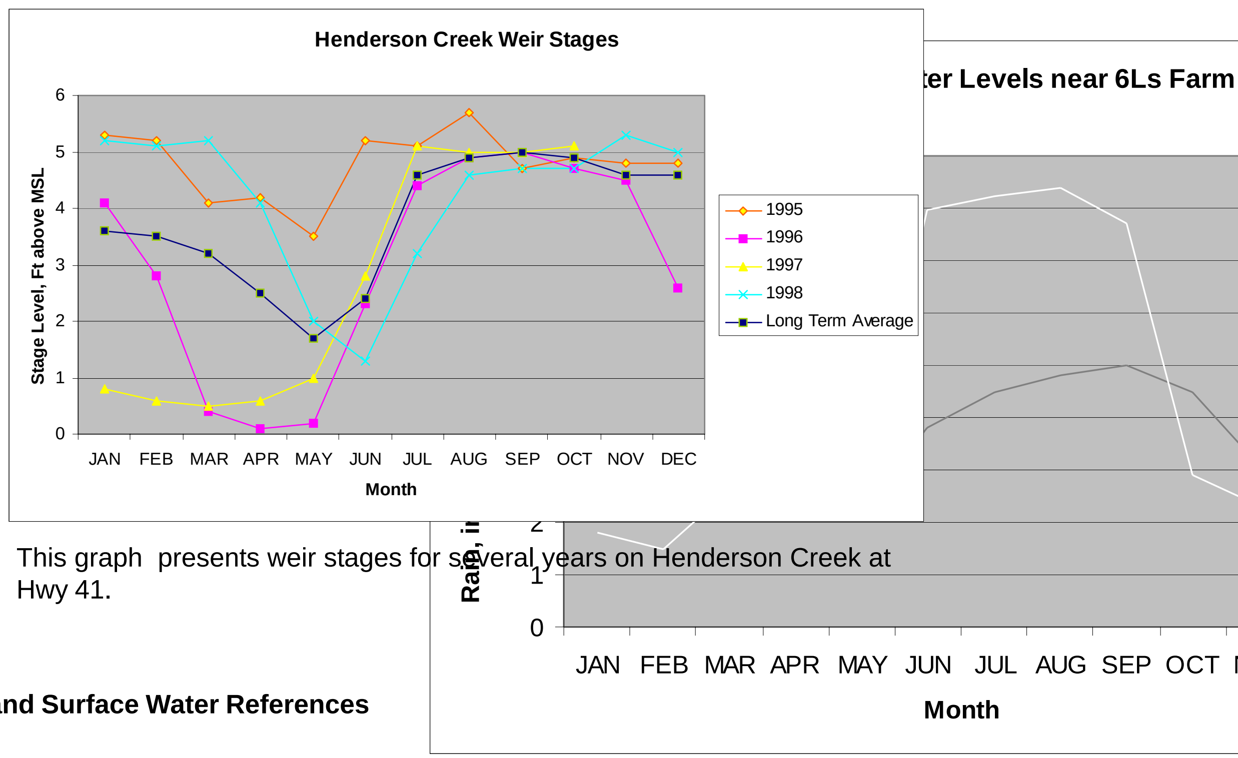
Historically, lakes are mostly absent from the watersheds in southwest Collier County due to the flat topography and largely absent solution holes prevalent in the rest of peninsular Florida. In natural coastal fringe and island areas, freshwater is scarce and ephemeral, and when pockets occur, they have important, if short-lived, ecological significance (Davis 1943). With the advent of retention areas and man-made lakes, an important shift in the wildlife, invertebrate and algal network is occurring. The long-term effects of this interference remain to be seen, but, as with canals, they are likely to be significant.





Rain graphs from weather stations close to RBNERR.

Long-term groundwater level and rainfall at a well near the Collier-Seminole State Park are compared. This well is just north of Hwy 41.



This graph presents weir stages for several years on Henderson Creek at Hwy 41.

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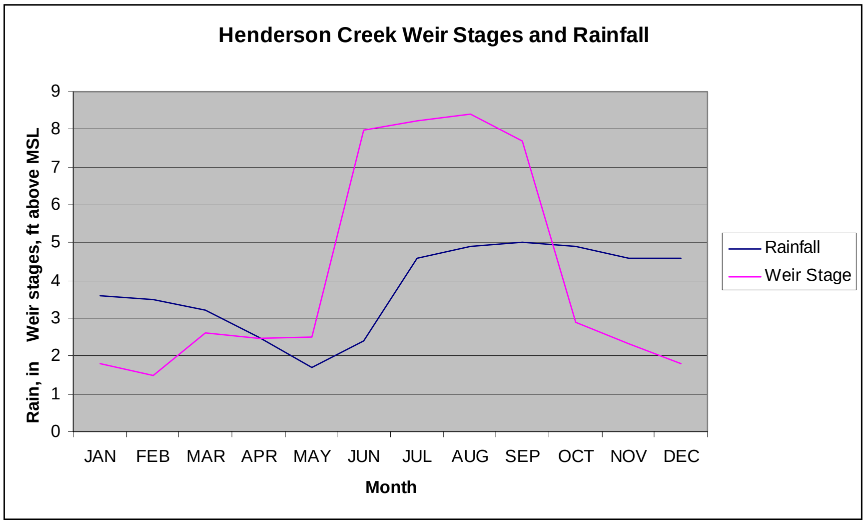

The bottom graph presents the long term average weir stage level with the long term average rainfall at the Collier County Landfill located directly north of the beginning of the Henderson Creek (951) Canal

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